CHAPTER II
THEORETICAL BACKGROUND AND LITERATURE SURVEY

2.1 Theoretical Background

2.1.1 Chitin and Its Derivatives

2.1.1.1 Chitin

Chitin is the second most prevalent natural biopolymer (after cellulose) which is obtained from entirely renewable natural raw materials. It forms a part of supporting tissues and exoskeletons of the arthropada (crustacea, arachnida), insects, cell wall of microorganisms, some fungi and water-plants where chitin is in complex with albumens and mineral salts. Chitin is a poly[β-(1-4)-2-acetamido-2-deoxy-*D*-glucopyranose] and its idealized structure is shown in Figure 2.1, from which it can be seen that it is structurally similar to cellulose except that C(2)-hydroxyl group of cellulose is replaced by acetamido group (Muzzaralli, 1977). That similarity in structure is reflected in the similar roles played by the two polymers in nature, both acting as structural and defensive materials.

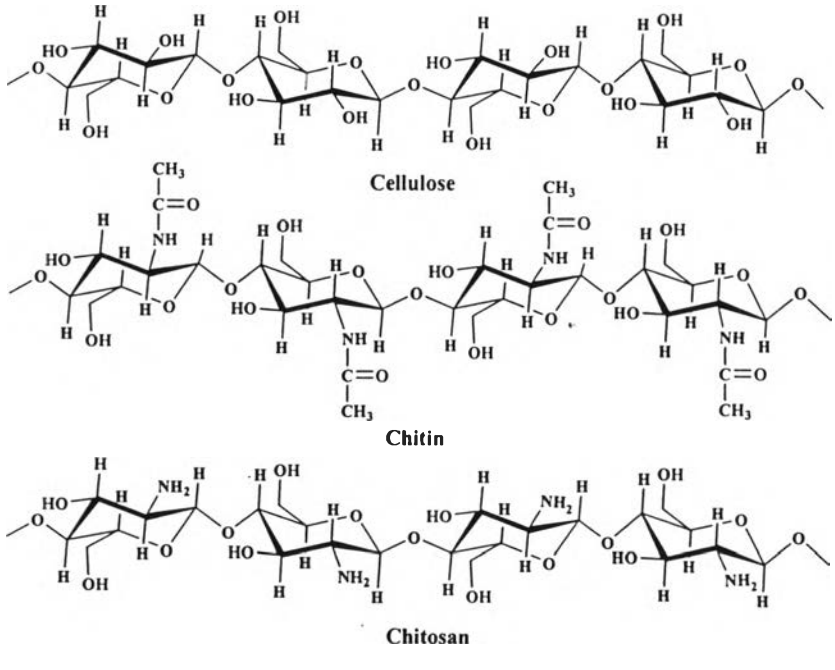

Figure 2.1 Chemical structures of cellulose, chitin and chitosan.

Chitin and its derivatives have many properties that make them attractive for a wide variety of applications, from food, nutrition and cosmetics to biomedicine, agriculture and the environment. Their antibacterial, anti-fungal and anti-viral properties make them particularly useful for biomedical applications, such as wound dressings, surgical sutures and as aids in cataract surgery and periodontal disease treatment.

2.1.1.2 Chitosan

Deacetylation of chitin by strong alkali readily affords chitosan, poly[β-(1-4)-2-amino-2-deoxy-*D*-glucopyranose]. However, the molecular structure of chitosan is believed to be a copolymer of *N*-acetyl-glucosamine and glucosamine, usually the glucosamine content is more than 90%. This polymer is known to be nontoxic, odorless, biocompatible in animal tissues, and enzymatically biodegradable. Much interest has been paid to its biomedical, ecological, and industrial applications. Because chitosan has an amino group in the repeating unit, it is soluble in aqueous acidic media. It has recently been used in biomedical and pharmaceutical fields because of its favorable properties of biodegradability, low toxicity, and good biocompatibility (Kumar, 2000).

2.1.1.3 Organic Solvent Soluble Chitosan

Chitosan has received much interest in biomedical applications, however, its rigid crystalline structure, poor solubility in organic solvents and poor processability have limited it to be utilized widely. In order to resolve these problems, chemical modification of chitosan, in particular, *N*-alkylation, *N*-acylation and O-acylation has been studied. Reportedly, in acyl modification chitosan reacted with long-chain acyl chloride for improving the organic solubility (Nishimura *et al.*, 1991). The acylated chitosans exhibited an excellent solubility in organic solvents such as chloroform, benzene, pyridine and tetrahydrofuran and transparent films were obtained from these solutions (Zong *et al.*, 2000).

2.1.2 Polylactide

Polylactide, PLA, biodegradable aliphatic polyesters, produced solely from renewable resources may substitute petrochemically based on polymers in a broad range of applications in the near future (Jacobsen *et al.*, 2000). PLA is hardly

permeable to most drugs and its half-life time is much shorter: a few weeks in vivo. It is of particular interest as a biocompatible material since it is metabolized to non-toxic compound. PLA is one of the polymers widely accepted for future packaging material. This is mainly due to the good mechanical properties of PLA. Moreover, PLA is produced from lactic acid, which can be prepared by fermentation from nearly any renewable resources such as starch, molasses, whey and sugar. Lactide is the cyclic dimer of lactic acid that exists as two optical isomers, D and L. L-lactide is the naturally occurring isomer, and D,L-lactide is the synthetic mixture of L-lactide and D-lactide. PLA is found in two forms: semicrystalline PL-LA and amorphous PD,L-LA.

The homopolymer of L-lactide is semicrystalline polymer. This type of materials exhibits high strength and low elongation, and consequently has a high modulus that makes them more suitable for load-bearing applications. High molecular weight PL-LA is of interest as a biodegradable thermoplastic and fiber forming material. Medical suture based on PL-LA are commercially available (Kricheldorf and Lee, 1995). PL-LA is about 37 % crystalline, with a melting point of 175-178°C and a glass-transition temperature of 60-65°C. The degradation time of PL-LA is much slower than that of PD,L-LA, requiring more than 2 years to be completely absorbed. Copolymers of L-LA and D,L-LA have been prepared to disrupt the crystallinity of L-LA and accelerate the degradation process. To meet various mechanical and degradation requirements, PLA must exhibit a broad spectrum of physical properties while retain the degradability of parent polymer.

There are several approaches for improving the properties of PLA, including blending and copolymerization of PLA. For example, the copolymer of PLA with poly(glycolic acid) has been produced to control the degradation rate through compositional modification. In recent years, there has been a growing interest in blending PLA with other polymers because blending is relatively simple and more cost-effective in comparison with copolymer synthesis. Through the opportune choice and composition of the second polymer, a tailor-made polymer with specific properties can be obtained. Several blending systems of PLA have been investigated previously, such as poly(L-lactide)(PLLA)/poly(ethylene oxide) (Nakafuku, 1996), PLLA/poly(vinyl alcohol) (Shuai *et al.*, 2001), PLLA/poly(*p*-

vinylphenol) (Zhang *et al.*, 1998), PLLA/poly(ε-hydroybutyrate) (Zhang *et al.*, 1996), and PLLA/poly(ethylene glycol) (Yang *et al.*, 1997).

2.1.3 Solution Properties of Polymers

The solution properties of polymers have been studied for many years. Early investigations were based on viscometric, osmometric, sedimentation, and light scattering intensity measurements.

2.1.3.1 Intrinsic viscosity

Intrinsic viscosity measurements are carried out in dilute solution to obtain the viscosity-average molecular weight. Consider such a dilute solution flowing down a capillary tube. The flow rate, and hence the shear rate, is different depending on the distance from the edge of the capillary. The polymer molecule, although small, is of finite size and 'sees' a different shear rate in different parts of its coil. This change in shear rate results in an increase in the frictional drag and rotational forces on the molecule, yielded the mechanism of viscosity increased by the polymer solution.

Several terms need defining. The solvent viscosity is η_0, usually expressed in poises. The viscosity of the polymer solution is η. The relative viscosity is the ratio of the two:

$$\eta_{rel} = \eta / \eta_0. \tag{2.1}$$

Of course, the relative viscosity is a quantity larger than unity. The specific viscosity is the relative viscosity minus one:

$$\eta_{sp} = \eta_{rel} - 1. \tag{2.2}$$

Usually η_{sp} is a quantity between 0.2 and 0.6 for the best results. The specific viscosity divided by the concentration (C) and extrapolated to zero concentration, yields the intrinsic viscosity:

$$[\eta_{sp} / C]_{C=0} = [\eta] \tag{2.3}$$

For dilute solution, where the relative viscosity is just over unity, the following algebraic expansion is useful:

$$\ln \eta_{rel} = \ln(\eta_{sp} + 1) \cong \eta_{sp} - (\eta^2_{sp} / 2) + \ldots \tag{2.4}$$

Then, dividing $\ln \eta_{rel}$ by C and extrapolating to zero concentration also yields the intrinsic viscosity:

$$[\ln(\eta_{rel})/c]_{c=0} = [\eta] \quad (2.5)$$

The intrinsic viscosity $[\eta]$ is a quantity characteristic of a polymer. It represents an increase in the solution viscosity when the concentration is raised to a certain level. A polymer molecule with a grater dimension has a larger $[\eta]$. Experimentally, it is expressed by Mark-Houwink equation (Teraoka, 2002):

$$[\eta] = K M_v^a \quad (2.6)$$

where "K" is a constant of the unit of L/g and "a" is called a Mark-Houwink exponent. Note that "K" and "a" are different from polymer to polymer and can depend on the solvent and temperature as well.

2.1.3.2 Dynamic Light Scattering (DLS)

Dynamic Light Scattering, also known as Photon Correlation Spectroscopy, is a useful means of determining a particle's size. Shinning a monochromatic light source onto particles in Brownian motion causes a Doppler Shift to occur. This changes the wavelength of the incoming light. This change is related to the size of the particle. By measuring the diffusion coefficient of the particle and using the autocorrelation function (a decaying exponential) the sphere size distribution (SSD) can be determined as well as a description of the particle's motion in the medium.

In dynamic light scattering experiments a normalized time autocorrelation function $g_2(\tau,q)$ of the scattered intensity was measured (Berne and Pecora, 1976):

$$g_2(\tau,q) = \frac{\langle I^*(0,q)I(\tau,q)\rangle}{\langle I(0,q)^2\rangle} \quad (2.7)$$

where $I(\tau,0)$ is the scattering intensity at a certain delay time from a reference time $t = 0$. In dilute solutions $g_2(\tau,0)$ can be expressed in terms of the normalized field correlation function $g_1(\tau,q)$ using the Siegert relationship

$$g_2(\tau,q) = 1+\beta|g_1(\tau,q)|^2 \quad (2.8)$$

where the coefficient $\beta < 1$ is the coherence factor. For short delay times $g_1(\tau,q)$ is well approximated by a single-exponential decay:

$$g_1(\tau,q) \approx \exp(-\Gamma(q)\tau) \text{ if } \Gamma(q)\tau < 1 \quad (2.9)$$

This decay rate Γ(q) is related to an apparent mutual diffusion coefficient as (Berne and Pecora, 1976; Zimm, 1948)

$$\Gamma(q) = q^2 D_{app}(q,c) \tag{2.10}$$

where

$$D_{app}(c,q) = D_{cm}(1 + CR_g^2 q^2 - \ldots) \tag{2.11}$$

D_{cm} is the diffusion coefficient of the particle's center of mass, where the subscript indicates the z-average over the molar mass distribution and q *is* the wavevector defined by $q = (4\pi/\lambda)n_o \sin(\theta/2)$ with n_o the refractive index, θ the scattering angle, and λ the wavelength of incident light. D_{cm} depends on concentration and is well represented by a linear relation:

$$D_{cm} = D_{cm}(1 + k_D c_p) \tag{2.12}$$

where k_D is the first-order concentration coefficient which depends on the second virial coefficient, A_2, and the hydrodynamic friction coefficient, ζ_1, given by (Teraoka, 2002)

$$k_D = 2A_2M - \zeta_1 - \nu_{sp} \tag{2.12}$$

where M is molecular weight of polymer., and ν_{sp} *is* the reciprocal of the density of the polymer.

The ratio $\Gamma(q)/q^2 \equiv D_{app}(c,q)$ is angular dependent and thus an apparent diffusion coefficient which is valid for small $q^2R_g^2 < 2$. This angular dependence results from segmental motions and polydispersity.

The double extrapolation of $D_{app}(c,q)$ in the limits of $c=0$ and $q=0$ can be alternatively done in a dynamic Zimm plot, giving the diffusion coefficient at infinite dilution, D_o, from which the hydrodynamic radius, R_H, can be obtained from the Stokes-Einstein relationship

$$R_H = \frac{k_B T}{6\pi\eta D_0} \tag{2.13}$$

where η is the solvent viscosity and k_BT is the Boltzmann constant multiplied by the absolute temperature.

2.1.4 Polymer Blend

Blending is an especially important process for developing industrial applications of polymeric materials and compatibility among components has a

marked influence on the physical properties of polymer blends (Folkes and Hope, 1985). Through a suitable choice of a pair of polymers, polymer blends can often be tailor-made to have specific and desirable properties.

In accordance with the theory of Flory-Huggins (Flory, 1953), the miscibility and compatibility of two polymers depend essentially in their ability to from specific interactions between them, which contributes to diminish or make negative the mixing enthalpy (ΔH_m). For example, the formation of hydrogen bonds between two different macromolecules competes with the formation of hydrogen bonds between molecules of the same polymer. The latter does not contribute to the ΔH_m. Then, it is expected that the intensity of the hydrogen bonding and the steric effect would be the determinants for the compatibility and miscibility of the two polymers

In general, polymers are immiscible with each other in the absence of specific interactions. The miscibility of a polymer blend is commonly ascertained by measurement of its glass transition temperature (T_g). A miscible polymer blend shows a composition-dependent T_g, while an immiscible blend shows two T_g's corresponding to those of the component polymers. For applications where mechanical integrity is required, miscible single-phase polymer blends are desirable. For some applications such as toughening of plastics, two-phase immiscible blends are required.

2.1.5 Electrospinning of Polymers

Unlike conventional fiber spinning techniques (wet spinning, dry spinning, melting spinning, and gel spinning) which are capable of producing polymer fibers with diameters down to the micrometer range, electrostatic spinning, or "electrospining" is a process capable of producing polymer fibers in the nanometer diameter range. Electrospinning is a novel and efficient fabrication process that can be utilized to assemble fibrous polymer mats composed of fiber diameters ranging from several micros down to fibers with diameter lower than 100 nm. Small fiber diameters and porous structures of the nonwoven mat of the electrospun fibers give rise to the large specific surface area (Deitzel *et al.*, 2001). This is advantageous in a wide variety of applications, such as high-performance

filters (Doshi and Reneker, 1995), scaffolds in tissue engineering (Buchko *et al.*, 1999), separation membranes, reinforcement in composite materials (Bergshoef and Vancso, 1999), templates for preparation of functional nanotubes (Bognitzki *el al.*, 2000), and many others.

In the electrospinning process a strong electrostatic field is applied to a polymer solution held in a syringe with a capillary outlet is deformed into a Taylor cone (Taylor, 1969), or more precisely, a hyperbolic cone (Yarin *et al.*, 2001), by the electrostatic field. When the voltage surpasses a threshold value, the electric forces overcome the surface tension on the droplet, and a charged jet of the solution is ejected from the tip of the Taylor cone. As the jet moves toward a collecting metal screen that acts as a counterelectrode, it is split into small charged fibers or fibrils (Reneker *et al.*, 2000), and the solvent evaporates. Thus, a nonwoven fabric mat is formed on the screen.

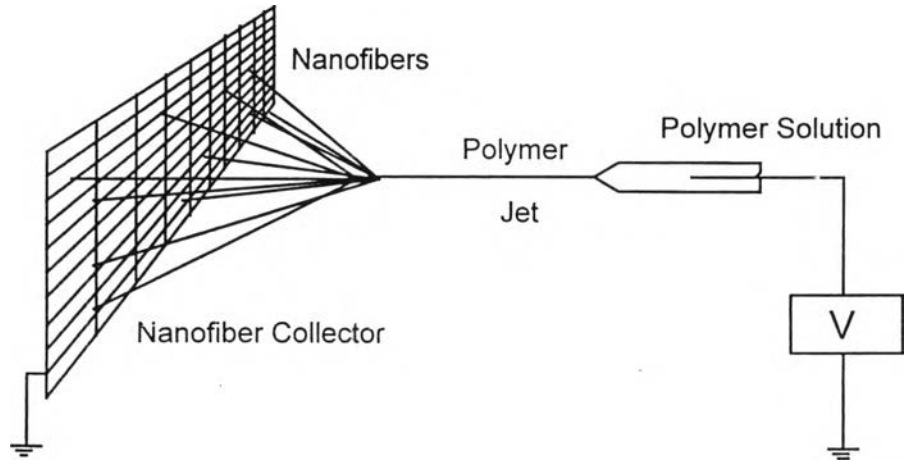

Figure 2.2 Schematic of the electrospinning process.

The following parameters and processing variables affect the electrospinning process: (i) System parameters such as molecular weight, molecular-weight distribution and architecture (branched, linear etc.) of the polymer and solution properties (viscosity, conductivity and surface tension), and (ii) Process parameters such as electric potential, flow rate and concentration, distance between the capillary and collection screen, ambient parameters (temperature, humidity an air

velocity in the chamber) and finally motion of target screen (Frenot, and Chronakis, 2003). For instance, the polymer solution must have a concentration high enough to cause polymer entanglements yet not so high that the viscosity prevents polymer motion induced by the electric field. The solution must also have a surface tension low enough, a charge density high enough, and a viscosity high enough to prevent the jet from collapsing into droplets before the solvent has evaporated. Morphological changes can occur upon decreasing the distance between the syringe needle and the substrate. Increasing the distance or decreasing the electrical field decreases the bead density, regardless of the concentration of the polymer in the solution. Applied filed can, moreover, influence the morphology in periodic ways, creating a variety of new shapes on the surface.

2.2 Literature Survey

2.2.1 Organic Solvent-Soluble Chitosan

Efficient procedures for the preparations of organic solvent-soluble chitosan derivatives have been established on the basic of chemical modifications. Solubility of chitosan derivatives in organic solvents is an essential requirement for effecting fine molecular design leading to novel types of functional materials. The removal of the two hydrogen atoms of amino groups of chitosan and introduction of some hydrophobic nature by chemical modification were changed chitosan's inherent crystalline structure and polarity. There are several researches that have been emphasized on chemical modification of the structure of chitosan.

Nishimura *et al.* (1991) prepared *N*-phathaloyl chitosan by the reaction of chitosan with phthalic anhydride in *N*,*N*-dimethylformamide (DMF) at 130°C. The modified chitosan obtained exhibited much improved solubility in common organic solvent such as DMF, *N*, *N*-dimethylacetamide, dimethyl sulfoxide, and pyridine.

Yalpani and Hall (1988) indicated that the attachment of carbohydrate to the 2-amino functions of chitosan transforms linear polymer into branched-chain polymers, which were soluble in both aqueous and organic solvents. This conversion can be achieved by reductive alkylation using sodium cyanoborohydride and any

aldehyde or keto sugar, by Shift base formation, or by amidation reactions using carboxylic acid or lactone derivatives. These procedures facilitate the chitosan exhibited a number of useful and uncommon properties in terms of their solution characteristics.

A simple and improved method of preparing highly soluble chitosan (half *N*-acetylated chitosan) was developed using a chitosan samples of low molecular weight, and the solubility of thc half *N*-acetylated chitosan in water and organic solvents was investigated. To reduce the molecular weight, chitosan was treated with $NaBO_3$ under the condition that chitosan was homogeneously dissolved in aqueous acetic acid. Chitosan was *N*-acetylated with acetic anhydride under the condition that chitosan was homogeneously dissolved in aqueous acetic acid again. The results indicated that half *N*-acetylated chitosan had increased water solubility with decreasing molecular weight and good solubility in aqueous dimethylacetamide and dimethylsulfoxide (Kubota *et al.*, 2000).

N-acyl chitosan had high susceptibility to lysozyme and showed more blood compatible properties than *N*-acetyl chitosan, in particular, *N*-hexanoyl chitosan was the most blood compatible (Lee *et al.*, 1995). Novel *N*-acylchitosan fibers were obtained by treatment the filament surface of chitosan fiber with a series of carboxylic anhydrides in methanol at room temperature. Their filament tenacity and elongation values were little influenced by the *N*-acylation (Hirano *et al.*, 1998).

Zong *et al.* (2000) synthesized three kinds of acylated chitosans by reacting chitosan with hexanoyl, decanoyl and lauroyl chlorides. In contrast to the chitosan, all of acylated chitosans showed excellent solubility in common organic solvents (table 2.1) such as halogenated hydrocarbons and aromatic solvents, but poor solubility in polar solvents. Thin transparent films could be obtained by casting their solutions in chloroform. The white chitosan film is rigid and tough; the films of the acylated chitosans are softer and become even more sticky and elastic at room temperature with increasing chain length of the acyl substituents.

Table 2.1 Solubility of chitosan and acylated chitosans (Zong *et al.*, 2000)

	Solubility									
	$CHCl_3$	CH_2Cl_2	C_6H_6	$C_6H_5CH_3$	Pyridine	THF	Dioxane	DMF	DMAc	DMSO
Chitosan	–	–	–	–	–	–	–	–	–	–
H-chitosan	+	+	+	±	±	±	Δ	Δ	Δ	Δ
D-chitosan	+	+	±	±	±	±	Δ	Δ	–	–
L-chitosan	+	+	±	±	±	±	Δ	Δ	–	–

Note: + : dissolved easily, ± : dissolved, Δ : swelling, – : not dissolved

2.2.3 Polymer Blend

Blending is an especially important process for developing industrial applications of polymeric materials and compatibility among components has a marked influence on the physical properties of polymer blends (Folkes and Hope, 1985). Through a suitable choice of a pair of polymers, polymer blends can often be tailor-made to have specific and desirable properties.

2.2.3.1 Effect of Blend Composition on Properties of Polymer Blends

Blending polymers can often have desirable effects on the product quality. However, this characteristic is quite dependent on the compatibility or miscibility of the components which are manifest in the crystallizability and the morphology, among other qualities of the polymer. The effect that blending has on polymer properties can be demonstrated using several studies of polymer blends. Pitt *et al.* (1992) reported that the hydrolysis rate, water content, and permeability coefficient of the blends from (50/50) poly(DL-lactide-co-glycolide) [P(DLLA-GA)] and water-insoluble poly(vinyl alcohol) (PVOH) increased with a rise in PVOH content, they concluded that P(DLLA-GA) and PVA were miscible when the P(DLLA-GA) content was smaller than 30wt.%. Nijenhuis *et al.* (1996) studied the

change in the mechanical and swelling properties of poly(L-lactide) (PLLA) upon the addition of a small amount of water-soluble poly(ethylene oxide) (PEO) up to 20 wt.%. Recently, Sheth *et al.* (1997) found that the weight loss rate of PLLA by enzymatic hydrolysis was significantly increased by the addition of a small amount of water-soluble PEO.

2.2.3.2 Effect of Solvent on Properties of Polymer Blends

Even though a large number of studies on solution-cast polymer blends are available in the open literature, only limited number are dedicated to study the effect of casting solvent on properties of the resulting blends. Bank *et al.* (1971) showed that films of polystyrene (PS)/poly(vinyl methyl ether) (PVME) blends appeared to be compatible when either toluene or benzene was used as the casting solvent, and they appeared to be incompatible when either trichloroethylene or chloroform was used. Asaletha *et al.* (1995) reported that the nature of the casting solvent had a profound effect on the compatibility behavior of natural rubber (NR)/polystyrene (PS) blends compatibilized by NR-g-PS. Radhakrishnan and Venkatachalapathy (1996) showed that the choice of the casting solvent used (e.g. dichloromethane, tetrahydrofuran, and toluene) to prepare the blend films of poly(ethylene oxide) (PEO) and poly(methyl methacrylate) (PMMA) not only affected the compatibility of the resulting films, but also the crystallization of PEO.

Also working with PEO/PMMA blends, Liau and Chang (2000) showed that PEO/PMMA blends were miscible when either benzene or chloroform was chosen as the casting solvent and that crystallization of PEO was found to be more suppressed when chloroform was selected. In blends of poly(vinyl acetate) (PVA) and PEO, Wu *et al.* (1997) reported that the resulting blends were miscible when benzene was used as the casting solvent and that crystallization of PEO was more easily suppressed when benzene was instead used, as evidenced by the fact that the interaction parameter of benzene-cast films showed a greater negative value than that of chloroform-cast ones. Tang and Liau (2000) studied the effect of casting solvent (e.g. acetone, tetrahydrofuran, isopropyl acetate, *n*-butanol, or cyclohexanone) on morphology and properties of poly(4-hydroxystyrene) and PEO blends and reported that, regardless of the solvent type, the blends were

miscible as evidenced by a single glass transition temperature observed and that crystallization of PEO was more suppressed when either tetrahydrofuran or cyclohexanone was used as the casting solvent.

2.2.4 Electrospinning of Polymers

The electrospinning process, invented by Formhals (1934), was studied in detail particularly by Reneker and coworker (Doshi, 1994; Doshi and Reneke, 1995; Reneker *et al.* 2000) as well as by Vancso and coworkers (Jaeger *et al.*, 1998) during the last decade. It has been found that the fiber diameter can be controlled within a broad range down to a few tens of nanometers by proper selection of processing parameters.

In the electrospining process of polymer solution, solvent is one of the main contributor for solution properties, e.g. conductivity. Water, a good solvent for poly(ethylene oxide) (PEO), has been successfully used in the electrospinning process of PEO (Fong *et al.*, 1999; Jaeger *et al.*, 1996; Shin *et al.*, 2001). When ethanol was added to water to attain mixed solvent systems, the diameters of the electrospun PEO fibers became bigger and the beaded fibers earlier observed disappeared (Fong *et al.*, 1999). The reason was claimed to the reduction of charge density carried by a charged jet and the increase in viscosity and evaporation rate of the mixed solvent, respectively. Dimethylformamide (DMF) was successfully used as a solvent for the electrospinning of polyacrylonitrile (Buchko *et al.*, 1999) and polyurethaneurea copolymer (Demir *et al.*, 2002); whereas, for biodegradable poly(*p*-dioxanone-co-L-lactide)-block-poly(ethylene glycol) copolymer, a mixed solvent of dichloromethane and DMF had to be employed (Bhattarai *et al.*, 2004). Solvents with high vapor pressures, e.g. carbondisulfide (CS_2), have been discussed as the cause of the observed nanoporous morphology of electrospun polystyrene fibers (Megelski *et al.*, 2002). Trichloromethane or chloromethane was found to be the best solvent for producing highly textured poly(methyl methacrylate) fibers (Megelski *et al.*, 2002). On the basis of these earlier reports, a fundamental study in pursuit of simple criteria for solvent selection is needed to obtain fibers with desired morphological characteristics.

The use of polymer nanofibers for biomedical applications is another active research area. In a recent publication, an electrospinning method was used by

Zong and co workers to fabricate bioabsorbable amorphous poly(D,L-lactic acid) and semi-crystalline poly(L-lactic acid) nanofibers nonwoven membranes for biomedical application (Xinhua *et al.*, 2002). They showed that the fiber diameter and the nanostructure morphology depended on processing parameters such as solution viscosity (e.g. concentration and polymer molecular weight), applied electric field strength, solution feeding rate and ionic salt addition. Concentration and salt addition were found to have relatively larger effects on the fiber diameter than that other parameters. A study on the fabrication of a scaffold by electrospinning biomedical such as PLA, poly(glycolic acid), poly(ethylene-co-vinyl acetate) (PEVA), type I collagen, was reported by Bowling *et al.* (2001). The use of electrospinning for tissue engineering is also another interesting field of application of polymer nanofibers. Most publications support that the electrospun nanofibrous structure is capable of supporting cell attachment and proliferation. Le *et al.* (2002) have developed an electrospun structure for tissue engineering applications, composed of poly(D,L-lactide-co-glycolide) PLGA fibers ranging from 500 to 800 nm in diameter.